Radio Waves and Sounding the Ionosphere - Part 1

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Radio is a fantastic invention; worldwide wireless contacts have been made for a century. Wireless by means of electromagnetic waves propagating through the atmosphere with the speed of light. It all began in the late 19th century. Many experiments and inventions by many scientists were the onset that finally leads to the first historical radio wireless communications. Further inventions and improvements were done and have made it today impossible to imagine life without radio communications. These communications are strongly influenced by many properties such as the ionosphere and solar activities. It was evident that researching these properties arose and led to a fuller insight of what radio and radio-wave propagation is.

In the forthcoming series I shall first pull your attention to the very beginning of radio and the investigations of the ionosphere. Later the various techniques of ionosphere investigation will be discussed and I will unveil the resulting ionograms by the ionosondes. These ionograms can give you about a lot of information and can tell you how your radio communications might or might not benefit from the instantaneous time properties.

A lot of historical data and scientists' biographies were found and compiled from the on internet Wikipedia encyclopedia and other interesting websites covering this subject. I strongly advise you to surf also around and read more about this fascinating history.

Some History

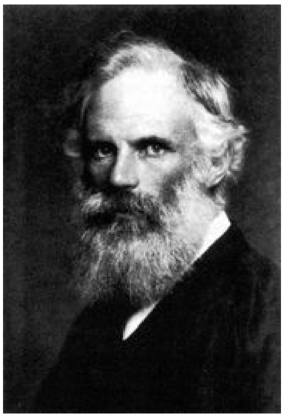
The Invention of the Radio

The physics of radio waves dates back to the work of ***James Clerk Maxwell*** who predicted electromagnetic waves and presented his theory in the form of the four Maxwell equations. In 1862 Maxwell pointed out that the theory indeed predicts waves consisting of electric and magnetic oscillations and propagating at a velocity that seemed to be equal to the speed of light. This suggested that ordinary light could consist of electromagnetic waves, but it also gave the possibility that electromagnetic waves could be essentially at lower frequencies, which could be generated by electric circuits.

James Clerk Maxwell (13 June 1831 – 5 November 1879) was a Scottish mathematician and theoretical physicist. His most significant achievement was formulating a set of equations — eponymously named Maxwell's equations — that for the first time expressed the basic laws of electricity and magnetism in a unified fashion.

The majority of Maxwell's illustrious career took place at the University of Cambridge, where his investigations often made use of his mathematical aptitude, drawing on elements of geometry and algebra. With these skills, Maxwell was able to demonstrate that electric and magnetic fields travel through space, in the form of waves, and at the constant speed of light. Finally, in 1861 Maxwell wrote a four-part publication in the *Philosophical Magazine* called On Physical Lines of Force where he first proposed that light was in fact undulations in the same medium that is the cause of electric and magnetic phenomena.

The generation of electromagnetic waves by electric circuits was first proposed by ***George Francis Fitzgerald*** in 1883, but the decisive experiments were made by ***Heinrich Hertz***, who published his results in 1888 – 1889, nearly ten years after Maxwell's death.



George Francis FitzGerald (3 August 1851 – 22 February 1901) was a professor of "natural and experimental philosophy" at Trinity College, Dublin, in the late 19th century.

Along with Oliver Lodge, Oliver Heaviside, and Heinrich Hertz, FitzGerald was a leading figure among the group of 'Maxwellians" who revised, extended, clarified, and confirmed James Clerk Maxwell's theory of the electromagnetic field in the late 1870s and 1880s. In 1883, following from Maxwell's equations, he suggested a device for producing rapidly oscillating electric current, to generate electromagnetic waves, a phenomenon first shown experimentally by Heinrich Hertz.

Heinrich Rudolf Hertz (February 22, 1857 - January 1, 1894) was the German physicist and for whom the hertz, an SI unit, is named. In 1888, he was the first to satisfactorily demonstrate the existence of electromagnetic radiation by building an apparatus to produce and detect UHF radio waves.

Through experimentation, he proved that transverse free space electromagnetic waves can travel over some distance. This had been predicted by James Clerk Maxwell and Michael Faraday. With his apparatus configuration, the electric and magnetic fields would radiate away from the wires as traverse waves. Hertz had positioned the oscillator about 12 meters from a zinc reflecting plate to produce standing waves. Each wave was about four meters. Using the ring detector, he recorded how the magnitude and wave's component direction vary. Hertz measured Maxwell's waves and demonstrated that the velocity of radio waves was equal to the velocity of light. The electric field intensity and polarity was also measured by Hertz

Earlier in 1886, Hertz developed a dipole antenna. This antenna is a center-fed driven element for transmitting or receiving radio frequency energy.

Hertz used an open resonator circuit (oscillator) with a spark gap as a transmitter and a conducting loop (resonator) with an adjustable gap as a receiver, **Fig. 63.1.** When a voltage in the oscillator circuit created sparks in the gap, high-frequency oscillations were generated and radio waves were transmitted. In the receiver loop these waves induced voltages high enough to create sparks in the receiver gap. The sparks in the receiver indicated the propagation of the waves from transmitter to the receiver. Further tests and experiments in his laboratory showed that the waves had the properties of ordinary light. They propagated rectilinearly in space, obeyed the reflection and refraction laws and could also be polarized.

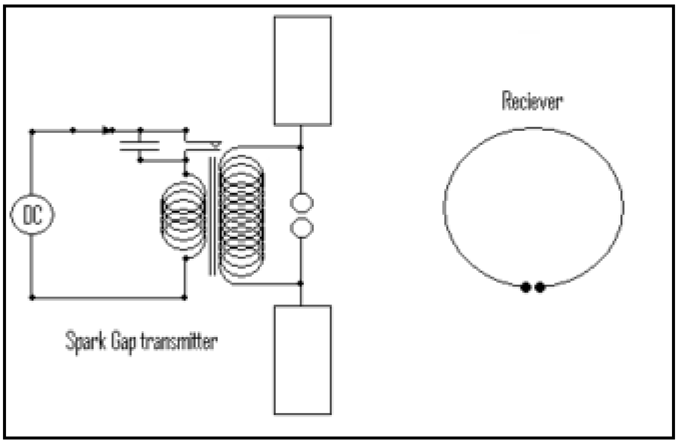


Fig. 63.1. *Hertz experiment setup.*

Hertz's interest in radio waves was purely scientific and he did not consider that his experiments could have any practical importance. His own words were:

"***I do not think that the wireless waves I have discovered will have any practical application.***"

When a relative suggested that a new type of telephone might be built using these waves. He rejected this possibility since he could not imagine how to create powerful electromagnetic waves at such low frequencies as those of human speech.

There were others who were more optimistic than Hertz, perhaps because they had not struggled with the experiments as Hertz had. His experiments raised wide interest and several scientists investigated the new type of electromagnetic waves. ***Oliver Lodge*** had already studied standing waves in conductors at the same time when Hertz carried out his experiments. Lodge's work was also inspired by Maxell's theory and he started to use the coherer, which was replacing Hertz's spark gap in the future radio receivers. Edward Branly invented the coherer in 1890. In 1894 Lodge demonstrated with a Hertz oscillator and his coherer the propagation of a signal at a distance of 150 meters. In spite of this success, he had also no interest in developing a wireless. Much later, in 1923 he wrote:

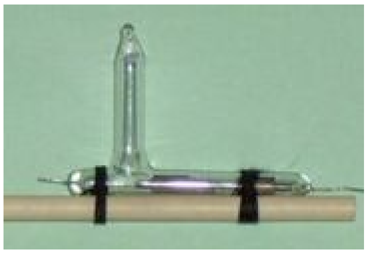
"I was too busy with teaching work to take up telegraphic or any other development. Nor had I the foresight to perceive what has turned out to be its extraordinary importance to the navy, the merchant service and indeed land and war service, too."

Another pioneer on the field was ***Augusto Righi***, who developed the oscillators and resonators and was able to go down to the wavelengths of 3 cm. Hence he can be considered as the father of microwave technique, Righi was a professor in Bologna, Italy and one of the pupils to come to his lectures was ***Guglielmo Marconi***. Also like Hertz and Lodge, Righi was interested in radio waves in a purely scientific sense, but at the same time he also affected the development of the radio by educating and encouraging its inventor.

Sir Oliver Joseph Lodge (June 12, 1851 - August 22, 1940), born at Penkhull in Stoke-on-Trent and educated at Adams' Grammar School, was a physicist and writer involved in the development of the wireless telegraph. Lodge, in his Royal Institution lectures ("*The Work of Hertz and Some of His Successors*") coined the term "coherer" and gained the "syntonic" (or tuning) patent from the United States Patent Office.

Lodge is notable for his work on the aether. He transmitted radio signals on August 14, 1894 at a meeting of the British Association for the Advancement of Science at Oxford University, one year before Marconi but one year after Tesla. Lodge improved Edouard Branly's coherer radio wave detector by adding a "trembler" which dislodged clumped filings, thus restoring the device's sensitivity. In 1995 the Royal Society recognized this scientific break through at a special ceremony at Oxford University.

Eugène Édouard Désiré Branly (23 October 1844 – 24 March 1940) was a French inventor and physicist. He was the Physics professor at the Catholic University of Paris. He is primarily known for his early involvement in wireless telegraphy and his invention of the Branly coherer around 1890.



The *coherer* was the first widely used detector for radio communication. Branly built upon the discoveries of Temistocle Calzecchi-Onesti, who demonstrated in experiments in 1884 through 1886 that iron filings contained in an insulating tube will conduct an electrical current under the action of an electromagnetic wave. The operation of the coherer is based upon the large resistance offered to the passage of electric current by loose metal filings, which decreases under the influence of radio frequency alternating current. The coherer became the basis for radio reception, and remained in widespread use for about ten years. This was used by, amongst others, Guglielmo Marconi, in his early experiments. Oliver Joseph Lodge improved Edouard Branly's coherer radio wave detector by adding a "trembler" which periodically dislodged clumped filings, thus restoring the device's sensitivity. The next innovation in electronic detection was Lee De Forest's Audion tube (1906) which replaced Branly device in many instances.

Augusto Righi (August 27, 1850-June 8, 1920) was an Italian physicist and pioneer of the study of electromagnetism.

Righi demonstrated his research studies while teaching at Bologna University. His name was often associated with that of Guglielmo Marconi, the inventor of the wireless telegraph, since it was said that the young inventor was a student of the illustrious professor, who taught in the same city. Although Marconi was not formally one of Righi's students, he certainly attended Righi's laboratory and the two had conversations on a number of physics experiments. With reference to electromagnetic waves, their work took them in very different directions. Righi's aim – to demonstrate their analogy to light waves – led him to develop short-wave optics, while Marconi's goal – to use electromagnetic waves to transmit signals over great distances – led him, instead, to use increasingly long wavelengths.

About the same time ***Alexander Popov***, inspired by Lodge's articles, constructed a receiver containing a coherer. He connected the receiver between a lightning conductor and the ground and was able to detect electromagnetic signals from thunderstorms. His equipment was generally known as the "storm detector". Popov described his receiver and coherer in a lecture given in May 1895. There was no mention of a transmitter in the available document on this lecture. In a later publication from January 1896, Popov wrote:

"Finally I wish to express my hope that my equipment after further improvements could be utilized in passing signals at a distance by means of electric undulations as soon as one has found a way to produce such undulations with a sufficient energy".

Alexander Stepanovich Popov (Russian) March 4, 1859 - December 31, 1905) was a Russian physicist who was the first to demonstrate the practical application of electromagnetic radio waves although he did not care to apply for a patent for his invention

Beginning in the early 1890s he continued the experiments of other wireless pioneers, such as Heinrich Hertz. In 1894 he built his first radio receiver, the coherer. Further refined as a lightning detector, it was presented to the Russian Physical and Chemical Society on May 7, 1895 — the day has been celebrated in the Russian Federation as "Radio Day". The paper on his findings was published the same year. In March 1896, he effected transmission of radio waves between different campus buildings in St Petersburg. Upon learning about Guglielmo Marconi's system, he effected ship-to-shore communication over a distance of 6 miles in 1898 and 30 miles in 1899.

This indicates that Popov seriously considered the possibilities of wireless, but it also tells that he had not yet developed a transmitter for that purpose, at least not before January 1896. It was later asserted that Popov had on 24 March 1896 transmitted and received Morse code at a distance of 100 m. This was before Marconi's patent. However, this information is undocumented and even if it is accepted, we must remember that Marconi had accomplished at least equally successful experiments already in autumn 1895. It is also indisputable that Popov had not published anything on a complete transmitter-receiver system before Marconi applied for his patent on 2 June 1896. However, this should not in no way reduce Popov's value and reputation as one of the pioneers of radio science.

Marconi started his experiments in June 1895. He improved the coherer considerably and used in the beginning a Righi-type oscillator with 25 cm waves and a parabolic mirror for directed transmissions. Next he replaced the oscillator with a simple spark gap, grounded one end of the secondary coil and connected the other end to a wire suspended in a mast. He found that the distance of reception was proportional to the square of the height of the mast or length of the wire. This was obviously the start of antenna techniques. By increasing the length of his antenna, Marconi could not only increase the transmitted power but also the wavelength. In September 1895 he managed with the help of these and other technical improvements to receive signals at a distance of 2.5 km.

Due to the lack of interest in his invention in Italy, Marconi moved to England and made a patent application in June 1896. The patent was granted a year later. The development of the equipment continued with English support; the achieved distance of reception was 7 km in autumn 1896, 14 km in May 1897, 50 km over the English Channel in March 1899, and 135 km later in the same year. When radio connection was established between the Isle of Wight and Cornwall at a distance of more than 300 km in January 1901, it became more and more clear that the connection was not due to direct rectilinear propagation of radio waves in the atmosphere. Then Marconi started to believe that transmissions over the Atlantic Ocean could be possible. A radio signal transmitted from Cornwall was indeed received on New Foundland in December 1901.

In spite of opposite predictions by qualified scientists, Marconi had succeeded in transmitting radio waves over the huge bulge of the Atlantic Ocean. This had been possible only because he was an inventor more than a scientist and he believed more in experiment than in theory. The search for the reason of his success was left to the scientists and, as a result of this study, we got a new topic of research: the ionosphere.

The Coherer

The filings coherer used in practical receivers was a glass tube filled about half full with sharply cut metal filings, often part silver and part nickel. Silver electrodes make contact with the metal particles on both ends. The electrodes are slanted so their effective spacing, filled by the filings, can be varied by rotating the tube about its long axis, thus adjusting its sensitivity verses false coherence performance to the prevailing conditions.

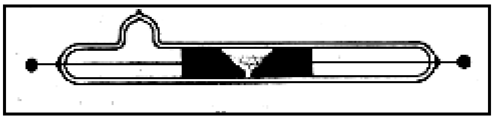


Fig. 63.2a. *The coherer: metal filings (dots) enclosed between two slanted electrodes (black) connected to terminals.*

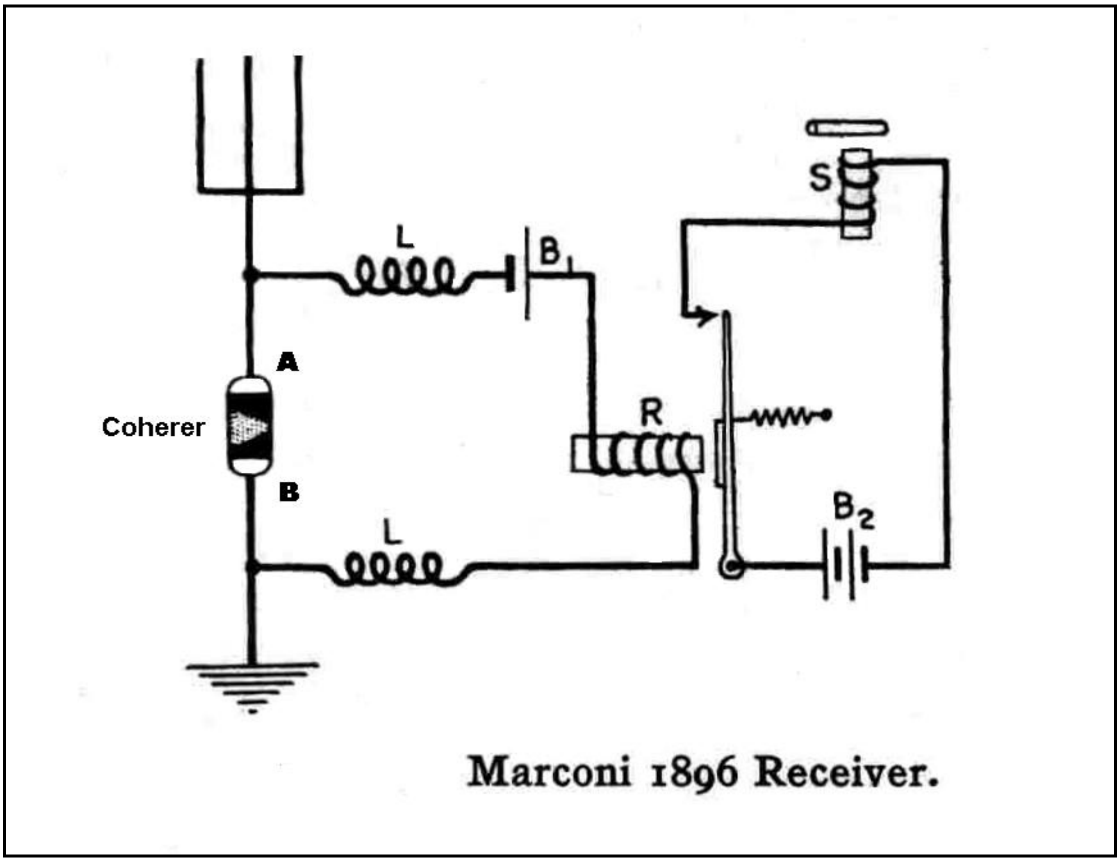


Fig. 63.2b. *The receiver using a coherer by Marconi.*

In operation, the coherer is included in two separate electrical circuits. One is the antenna-ground circuit shown in the untuned receiver circuit, **63.2b**. The other is the battery-sounder relay circuit including battery B1 and relay R in the diagram. A signal in the antenna-ground circuit enables current flow in the battery-sounder circuit activating the sounder, S. The coils, L, acts as RF chokes to prevent the RF signal power from leaking over to the relay circuit.

One electrode, A, of the coherer, **Fig. 63.2a** and **63.2b,** is connected to the antenna and the other electrode, B, to ground. A series combination of a battery, B1 and a relay, R, is also attached to the two electrodes. When the signal from a spark gap transmitter is received, the filings tend to cling to each other reducing the resistance of the coherer. When the coherer conducts better, battery B1, supplies enough current through the coherer to activate relay, R, which connects battery B2 to the telegraph sounder, S, giving an audible click. In some applications, a pair of headphones replaced the telegraph sounder, being much more sensitive to weak signals.

Guglielmo Marconi, (25 April 1874 - 20 July 1937) was an Italian inventor, best known for his development of a radiotelegraph system, which served as the foundation for the establishment of numerous affiliated companies worldwide. He shared the 1909 Nobel Prize in Physics with Karl Ferdinand Braun, "in recognition of their contributions to the development of wireless telegraphy".

Around the turn of the century, Marconi began investigating the means to signal completely across the Atlantic, in order to compete with the transatlantic telegraph cables. Marconi soon made the announcement that on 12 December 1901, using a 122-metre (400-foot) kite-supported antenna for reception; the message was received at Signal Hill in St John's, Newfoundland (now part of Canada) signals transmitted by the company's new high-power station at Poldhu, Cornwall. The distance between the two points was about 3,500 kilometers (2,100 miles). Although widely heralded as a great scientific advance, there was also some skepticism about this claim, in part because the signals had only been heard faintly and sporadically. In addition, there was no independent confirmation of the reported reception, and the transmission, which merely consisted of the three dots of the Morse code letter *S* sent repeatedly, came from a transmitter whose signals were difficult to differentiate from the noise made by atmospheric static discharges. (A detailed technical review of Marconi's early transatlantic work appears in John S. Belrose's work of 1995.) The Poldhu transmitter was a two-stage circuit. The first-stage possessed lower voltage and provided the energy for the second stage in resonance. Nikola Tesla, a rival in transatlantic transmission, stated after being told of Marconi's reported transmission that "Marconi [... was] using seventeen of my patents."

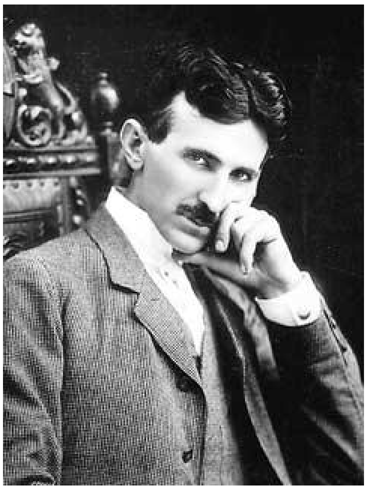
Feeling challenged by skeptics, Marconi prepared a better-organized and documented test. In February, 1902, the *S.S. Philadelphia* sailed west from Great Britain with Marconi aboard, carefully recording signals sent daily from the Poldhu station. The test results produced coherer-tape reception up to 2,496 kilometers (1,551 miles), and audio reception up to 3,378 kilometers (2,099 miles). Interestingly, the maximum distances were achieved at night, and thus these tests were the first to show that, for medium wave and long wave transmissions, radio signals travel much farther at night than during the day. During the daytime, signals had only been received up to about 1,125 kilometers (700 miles), which was less than half of the distance claimed earlier at Newfoundland, where the transmissions had also taken place during the day. Because of this, Marconi had not fully confirmed the Newfoundland claims, although he did successfully prove that radio signals could be sent for hundreds of kilometers, in spite of the fact that some scientists had believed they were essentially limited to line-of-sight distances.

On 17 December 1902, a transmission from the Marconi station in Glace Bay, Nova Scotia, Canada, became the first radio message to cross the Atlantic in an eastward direction. On 18 January 1903, a Marconi station built near Wellfleet, Massachusetts in 1901 sent a message of greetings from Theodore Roosevelt, the President of the United States, to King Edward VII of the United Kingdom, marking the first transatlantic radio transmission originating in the United States. However, consistent transatlantic signaling turned out to be very difficult to establish.

Marconi hereabout began to build high-powered stations on both sides of the Atlantic Ocean, in order to communicate with ships at sea in competition with other inventors. In 1904, a commercial service was established to transmit nightly news summaries to subscribing ocean-going ships, which could incorporate them into their on-board newspapers. A regular transatlantic radiotelegraph service was finally announced in 1907, but even after this the company struggled for many years to provide reliable communication.

The problem of the filings continuing to cling together after the removal of the RF energy was solved by tapping the coherer with a small mallet attached to the sounder after the arrival of each signal shaking up the filings and raising the resistance of the coherer to the original value. In practical implementations, the decoherer was the clapper of a doorbell that was powered by the coherer current itself. This is referred to as decohering and was subject to much innovation during the life of this component. Tesla, for example had the tube rotating continuously along its axis, following each successive activation.

Nikola Tesla ((10 July 1856 - 7 January 1943) was a world-renowned inventor, physicist, mechanical engineer and electrical engineer. He was born an ethnic Serb subject of the Austrian Empire, and later became an American citizen. Tesla is best known for his many revolutionary contributions to the discipline of electricity and magnetism in the late 19th and early 20th century.



After his demonstration of wireless communication in 1893 and after being the victor in the "War of Currents", he was widely respected as America's greatest electrical engineer. Much of his early work pioneered modern electrical engineering and many of his discoveries were of groundbreaking importance. In the United States, Tesla's fame rivaled that of any other inventor or scientist in history or popular culture, but due to his eccentric personality and, at the time, unbelievable and sometimes bizarre claims about possible scientific and technological developments, Tesla was ultimately ostracized and regarded as a *mad scientist*. Never putting much focus on his finances, Tesla died impoverished at the age of 86.

Further developments

Once started, the technical development of the radio was fast. Based on the Edison effect discovered by ***Thomas Alva Edison*** already in 1883, ***John Ambrose Fleming*** invented the diode in 1904. A starting point for the amplification technique was provided by the discovery of the triode in 1906 by ***Lee de Forest***. In order to improve the low gain of the first triodes, ***Edwin Howard Armstrong*** introduced the principle of positive feedback ('regenerative circuit') in 1912. Of course, this also led to the discovery of an oscillator, which for the first time gave a possibility for electronic generation of clean continuous radio waves. The modulator by ***R.A. Heising*** followed in 1913, and the super heterodyne receiver, again by ***Armstrong***, in 1918. In order to minimize distortion and stabilize the gain, ***H.S. Black*** developed the negative-feedback amplifier in 1927. Still in 1930 ***Armstrong*** gave an important contribution to radio technology by introducing the frequency modulation principle.

Raymond A. Heising was born August 10, 1888, at Albert Lea, Minn. He received a degree in electrical engineering from the University of North Dakota in 1912 and the master's degree from the University of Wisconsin in 1914.

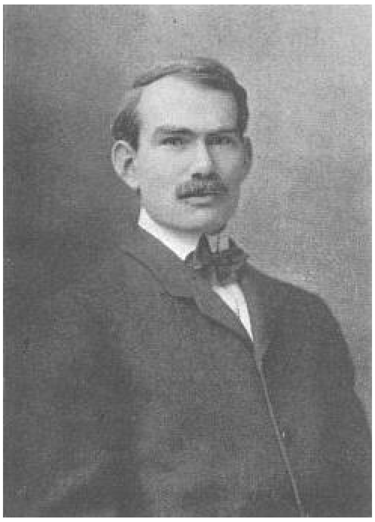
From 1914 until his retirement in 1953, Dr. Heising was associated with the Western Electric Company and Bell Telephone Laboratories. He played a major role in the development of radiotelephone systems for military use in World War I, and for transoceanic and ship-to-shore public service use. He also conducted much research work on ultra-short waves, electronics and piezoelectric crystal devices. He invented several modulation systems which are still in wide use today: the constant potential system, the grid modulation system for radio, the rectifier modulation system used in carrier telephony, and in particular, the constant-current or Heising modulation system. He has over one hundred United States patents, including the patents on the Class C amplifier and diode-triode detector amplifier circuit, and has published numerous technical papers in engineering journals.

Sir John Ambrose Fleming, (November 29, 1849 - April 18, 1945) was an English electrical engineer and physicist. He was born John Ambrose Fleming on November 29, 1849

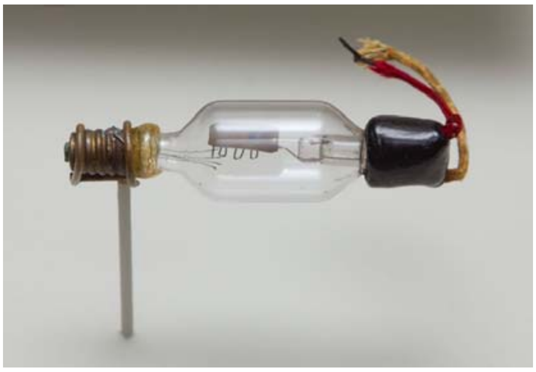
In November 1904, he invented and patented the two-electrode vacuum-tube rectifier, which he called the oscillation valve. It was also called a thermionic valve, vacuum diode or Fleming valve. This invention is often considered to have been the beginning of electronics, for this was the first vacuum tube. Fleming's diode was a vital unit in radio receivers and radars for many decades afterwards, until solid-state electronic technology took over.

In 1906, Lee De Forest of the USA added a control "grid" to the valve to create a vacuum tube RF detector called the *Audion*, leading Fleming to accuse him of copying his ideas. De Forest's device was shortly refined by him into an amplifier tube called the triode. The triode was vital in the creation of long-distance telephone and radio communications, radars, and early digital computers.

Lee De Forest, (August 26, 1873 – June 30, 1961) was an American inventor with over 300 patents to his credit. De Forest invented the Audion, a vacuum tube that takes relatively weak electrical signals and amplifies them. De Forest is one of the fathers of the "electronic age", as the Audion helped to usher in the widespread use of electronics.



De Forest invented the Audion in 1906, an improved version of John Fleming's recently invented diode vacuum tube detector. In January 1907, he filed a patent for a three-electrode version of the Audion, which was granted US Patent 879,532 in February 1908. It was also called the De Forest valve, and since 1919 has been known as the triode.



De Forest's innovation was the insertion of a third electrode, the grid, in between the cathode (filament) and the anode (plate) of the previously invented diode. The resulting triode or three-electrode vacuum tube could be used as an amplifier for electrical signals, and, equally important, as a fast (for its time) electronic switching element, later applicable in digital electronics (such as computers). The triode was vital in the development of long-distance (e.g. transcontinental) telephone communications, radio, and radars. The triode was an important innovation in electronics in the first half of the 20th century, between Nikola Tesla's and Guglielmo Marconi's progress in radio in the 1890s, and the 1948 invention of the transistor.

Harold Stephen Black (1898-1983) was an electrical engineer who revolutionized the field of applied electronics by inventing the negative feedback amplifier in 1927. To some, his invention is considered the most important breakthrough of the twentieth century in the field of electronics, since it has a wide area of application. This is because all electronic devices (vacuum tubes, bipolar transistors and MOS transistors) invented by mankind are basically nonlinear devices. It is the invention of negative feedback, which makes highly linear amplifiers possible. Negative feedback basically works by sacrificing gain for higher linearity (or in other words, smaller distortion). By sacrificing gain, it also has an additional effect of increasing the bandwidth of the amplifier. However, a negative feedback amplifier can be unstable such that it may oscillate

Edwin Howard Armstrong (December 18, 1890 – January 31, 1954) was an American electrical engineer and inventor. Armstrong was the inventor of the FM radio.

Armstrong was one of the most prolific inventors of the radio era, with a vision that was ahead of his time. He invented the Regenerative circuit (invented while he was a junior in college at Columbia University, New York City, and patented 1914), the Super-regenerative circuit (patented 1922), and the Super heterodyne receiver (patented 1918). The latter was developed when Armstrong was in the Army during World War I. Stationed in France, he rose to the rank of major.

In the first decade of the 20th century, radio communications became a fact. A lot was still unknown about the propagations properties of these radio waves. Many hypothesis and assumptions were put forth in that early stage concerning the wave paths. It took nearly 20 years to prove that there was an ionospheric reflector influencing most radio wave paths. The historical experimental story of this research is the next coming episode. Stay tuned.

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